Colouring of Dolomite, Quartzite and Dolerite Mine Dump Rocks

Z. Easton, F.B. Waanders and E. Fosso-Kankeu

***Abstract*— For environmental and aesthetic purposes it has become essential that mine dump rocks either blend into the environment or be used in the production of other products. Lately, there has been a constant need to produce more durable road and construction material and to develop an alternative for granite countertops and flooring. For the visibility of road surface material and the aesthetic aspect of countertops, the colouring of mine dump rocks was considered. A cost effective and environmentally friendly process was suggested to colour mine dump rocks. In this study different colouring agents for three mine dumping rocks, dolomite, quartzite and dolerite, were investigated. The aim was to create lasting colours that have a high wear resistance to weather conditions. Coloured dolomite can be used as road and construction material, coloured quartzite as countertops while coloured dolerite can serve as a replacement for road surfaces.**

***Keywords*—** Dolerite, Dolomite, Mine dump rocks, Quartzite, Rock colouring

I. Introduction

Despite intensive studies conducted on the rock types dolomite, quartzite and dolerite, as well as studies related to pigmentation and differential staining of minerals, the staining of rock types for industrial use and aesthetic purposes are still controversial. Furthermore, the lack of results regarding the weathering rates of coloured rock fragments substantiate the necessity to explore this field of study. Previous studies also brought forth certain limitations that needs to be considered. These limitations include the diversity of pigments used for rock colouring, the environmental friendliness of the staining methods and the economical aspect surrounding the potential industrial use of these coloured rocks. It is emphasized that harmful paints and pigments are continuously replaced with environmentally friendly products and that relevant studies should remain competitive regarding economics [1]. New uses for materials are constantly considered. Dolomite and dolerite are both used for road and construction material, whereas quartzite is a possible source for countertops. All three rock types are formed through different processes, consist out of different minerals and possess different chemical as well as physical properties. Therefore, it can be concluded that each rock type will react differently to various colouring techniques and pigments.

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Dolomite rocks, also known as dolostones, are sedimentary rocks which consist mainly out of the mineral dolomite [2]. Sedimentary rocks are formed when accumulated mineral fragments, dissolved compounds and dust are chemically bonded and solidified through compression [3]. Impurities, including calcite, iron, manganese, feldspar and quartz, may be present within the dolostones, depending on the region where the rocks were located [4]. Analytical data obtained from a previous study conducted at the NWU Potchefstroom Campus indicates the composition of dolomite, $CaMg(CO_3)_2$, from the Potchefstroom area to be as follows: 30.8% CaO, 22.3% MgO and 46.9% CO_2 [5].

Quartzite can either be classified as a metamorphic or a sedimentary rock type, depending on the formation process of the rock. Orthoquartzite refers to quartzite of sedimentary origin formed by diagenesis; the conversion of sediment to sedimentary rock [6]. Metaquartzite is a metamorphic rock type formed due to an incorporation of deformation and recrystallization [2 – 7]. Quartzite contains more than 80% quartz or SiO_2 [6]. The mineral quartz consists out of conchoidal fractures and the colour of quartz is usually white or colourless [4]. Other colours that do occur are mainly caused by impurities. Quartz has the constant composition of 46.7% Si and 53.3% O [4].

Diabase refers to the dark igneous rock found in shallow intrusions, below the earth's surface. Diabase resembles gabbro in all aspects except that diabase is finely phaneric, where gabbro is coarsely phaneric [7]. Exposed to the atmosphere, these finely phaneric rocks with basaltic composition, are better known as dolerites. The dark colour is due to the mafic minerals that constitutes to 50% of the rock, whereas feldspar constitutes the remainder of the composition [7]. The major components present in dolerite are plagioclase and pyroxene. Other components such as either olivine or quartz, as well as opaque minerals and alkali feldspar may also be present. Dolerite usually consist of 62% plagioclase, 20% - 29% pyroxene, 12% olivine, 2% magnetite and 2% ilmenite [8].

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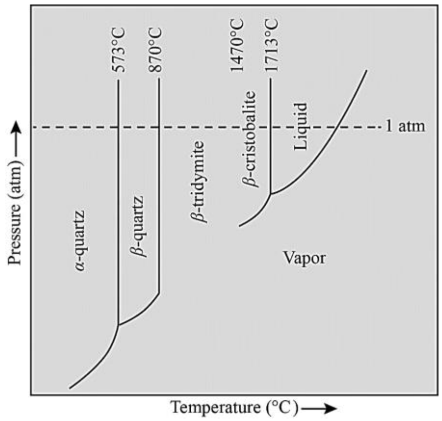

Fig. 1. Unary phase diagram of SiO_2 [9].

In the present investigation the constant improvement of durability and weathering resistance of the coloured rocks should be evaluated. To avail in the success of the colouring methods and decrease in the weathering rate, heat treatment is considered to aid in the staining process. Several studies have been conducted on the analysis of heat treatment on rocks. Heat treatment induce changes in physical properties of quartz fragments, which can evidentially influence the results of quartzite staining. Fig. 1 indicates the temperature-pressure diagram for quartz. It is indicated in the figure that at a pressure of 1atm and a temperature of 573°C, the alpha-quartz will transition to beta-quartz [9]. It is further indicated that at a temperature of 870°C the beta-quartz will transition to beta-tridymite. At a temperature exceeding the 573°C mark, trans-granular cracks are induced in quartz as well as feldspar grains which will induce a deeper cross-sectional colouring of the fragment.

II. EXPERIMENTAL

A. Materials and Solutions

All rock fragments used in this experimental study were sourced from the North West province in South Africa. Quartzite rocks, already fragmented in sizes 9.5 mm and 13 mm, were supplied by a mine in the Stilfontein area, 36 kilometres from Potchefstroom, South Africa. Dolerite and dolomite rocks were obtained from the Potchefstroom area. The dolerite and dolomite rocks needed to be crushed into desirable sizes before further experiments on the fragments could occur. The colouring agents used are tartrazine, congo red, ferric chloride, methylene blue and basic fuchsin. All the colouring agents occur in powder form and should be dissolved using certain solvents. The solvents used in the experiments include distilled water, diluted and concentrated hydrochloric acid, methanol/ethanol and caustic soda solution which is added to the alcohol solution when staining dolomite with organic dyes.

B. Sample Preparation

Dolerite and dolomite rocks were first broken into smaller sections with an industrial sledge hammer. The smaller sections where then send through a jaw crusher to obtain the preferred size fragments. A jaw crusher has two distinctive plates set at an acute angle. While one jaw remains fixed, the other jaw is pivoted to create an oscillating effect in relation to the fixed jaw [10]. After the dolerite and dolomite rocks were crushed, the fragments where separately ordered into fine and coarse fragments through dry screening. The dolomite rock fragments were etched in diluted hydrochloric acid. The duration of the etching was 5 minutes. Through etching the surface of the rock fragment corrodes, ensuring the staining adheres to the surface. The etching occurs in diluted hydrochloric acid consisting of 7.4ml concentrated HCl diluted in 51.7ml water.

C. Experimental Procedure: Phase 1

Two samples of each rock type were tested with colouring methods without inducing a specific elevated temperature into the colouring process. For the first dolomite sample, 0.2g tartrazine dissolved in 19.7g methanol was added to 100g caustic soda solution. For the second dolomite sample, 0.2g congo red dissolved in 19.7g methanol was added to 100g caustic soda solution. For the first quartzite sample, 5g ferric chloride was dissolved in 59.1g diluted hydrochloric acid. For the second quartzite sample, 2g methylene blue was added to 100g distilled water. For the first dolerite sample, 5g ferric chloride was dissolved in 59.1g diluted hydrochloric acid. For the second dolerite sample, 5g ferric chloride was dissolved in 59.1g diluted HCl. The rock fragments were submerged in the specific solutions. The fragments were left in the solution for 14 days before removing it and placing the coloured fragments outside to study its effect in weathering conditions.

D. Experimental Procedure: Phase 2

During the Phase 2 experiments, only dolomite and quartzite samples were used, due to the dolerite fragments having no distinct single mineral composition. In Phase 2 the influence of temperature during the colouring procedure was studied. For dolomite two solutions were prepared; 10g tartrazine dissolved in 250g ethanol and 10g congo red dissolved in 250g ethanol. After the addition of the dolomite fragments to the solutions, the solutions were placed on a hot plate and heated to just above the boiling point of ethanol. The temperature of each solution as well as the temperature of the hot plate is measured with a thermocouple. After boiling the solution for 55 minutes, the fragments remained in the solution, at room temperature, for 14 days before being removed. For quartzite two solutions were also prepared. These solutions were 25g ferric chloride added to 528.63g diluted hydrochloric acid and 2g methylene blue added to 500g distilled water. The quartzite fragments were quench-crackled. This procedure entails heating the fragments to 700 °C with an acethylene torch and directly submerging the fragments into the colouring solutions.

E. Weathering Conditions

Both phase 1 and phase 2 samples were place outside to determine if certain weather conditions influence the weathering of the coloured rocks. Fig. 2 indicates the temperature and rainfall data recorded over a duration of the 60 days weathering exposure.

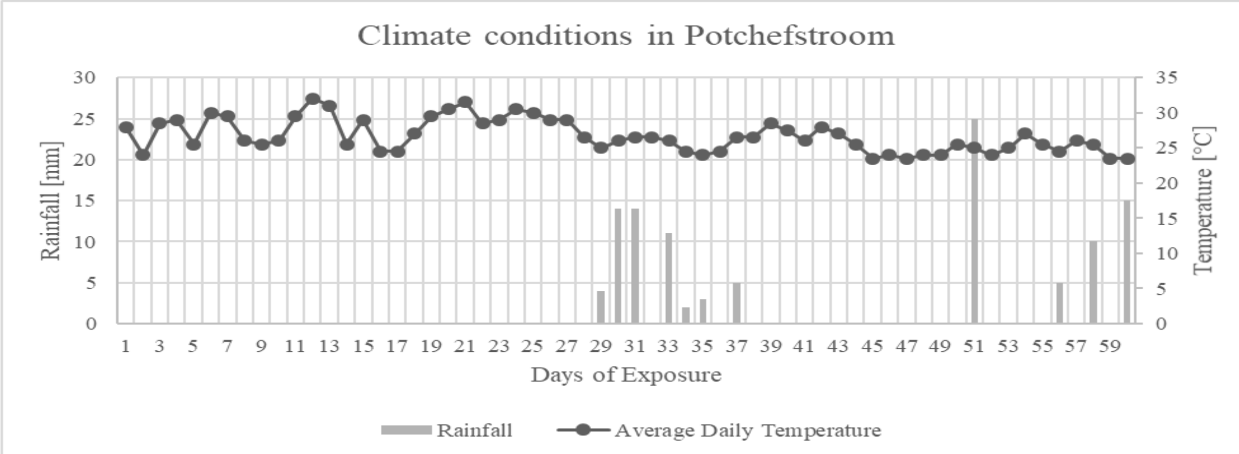

Fig. 2. Rainfall and temperature data obtained for the Potchefstroom area.

III. RESULTS AND DISCUSSION

Results were obtained through EDS analysis done with the QUANTA FEG 250 SEM Analyser to determine the exact composition of the coloured rock fragments and compare it to the composition of the original fragments. Secondary images were captured with the SEM to show the topography of the rock fragments and back-scatter images were captured to indicate the light and heavy minerals within the samples.

A. *Results: Dolerite Staining*

Table I shows the EDS data obtained for an original (O) dolerite fragment and two dolerite fragments coloured in phase 1 (P1). These fragments include a fragment coloured with ferric chloride and a fragment coloured with basic fuchsin. The colouring of the dolerite fragment with ferric chloride ($FeCl_3$) induces an increase in the component weight % of iron (Fe) from 11.94% to 31.89% as well as a 2.02% increase of chloride (Cl).

TABLE I: DOLERITE ANALYSIS ON THE OUTER SURFACE

Dolerite – Ferric Chloride										
	Component Weight %									
	Si	**O**	**Ca**	**Mg**	**Fe**	**Al**	**Na**	**K**	**S**	**Cl**
O	25.7	44.3	4.65	11.6	11.9	1.61	0.24	0	0	0
P1	15.7	37.8	1.93	0.87	31.9	7.39	0.32	0.66	1.38	2.05

Dolerite – Basic Fuchsin								
	Component Weight %							
	Si	**O**	**Ca**	**Mg**	**Fe**	**Al**	**Na**	**K**
O	23.45	44.03	6.71	6.48	10.26	7.90	1.17	0
P1	28.48	45.21	4.27	2.32	11.43	6.34	1.45	0.5

This significant increase indicates that a thick layer of ferric chloride remains on the rock surface even after the coloured rock has been exposed to weathering. Comparing data of the original fragment with the basic fuchsin fragment, presented no significant change in composition. One would expect to see small amounts of chloride in the basic fuchsin ($C_{20}H_{19}N_3HCl$) fragment, but chloride is not detected due to the hydrochloric form in which the basic fuchsin is found. When evaluating the cross section of the coloured fragments, no colour changes within the fragments were detected.

B. *Results: Dolomite Staining*

In phase 1 of the dolomite staining process, both tartrazine and congo red stained only the outer layer of the dolomite. Fig. 3 shows a SEM back-scatter image of dolomite stained with congo red in phase 1. The light sections of the image indicate the weathering of the colouring agent were the dolomite surface became visible. The dark sections indicate the congo red which remained after the fragment was exposed to weather conditions. Due to the excessive weathering of the colour, the phase 2 experiments were conducted with the addition of heat. In phase 2 the impact of temperature on the successful staining of the fragments were observed.

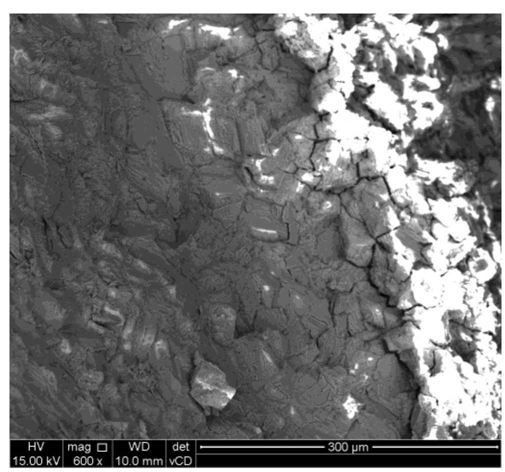

Fig. 3. Dolomite with congo red back-scatter image.

TABLE II: DOLOMITE ANALYSIS ON THE OUTER SURFACE

	Dolomite - Tartrazine											
	Component Weight %											
	C	O	Ca	Mg	Na	Al	Si	S	Cl	K	Fe	Mn
Original	20.79	63.34	8.79	5.49	0.06	0.12	0.3	0.06	0.06	0.08	0.51	0.40
Phase 2	23.51	55.41	10.54	7.17	0.61	0.12	0.32	0.58	0.58	0.04	0.76	0.36
	Dolomite – Congo Red											
	Component Weight %											
	C	O	Ca	Mg	Na	Al	Si	S	Cl	K	Fe	Mn
Original	20.79	63.34	8.79	5.49	0.06	0.12	0.30	0.06	0.06	0.08	0.51	0.40
Phase 2	21.32	58.48	10.63	8.36	0.10	0.06	0.27	0.18	0	0	0.11	0.49

Table II indicates the differences in composition from the original fragment to the coloured fragment of phase 2. The Ca-Mg-CO_2 ratio correlates with the ratio determined in previous experiments conducted by the NWU Potchefstroom Campus. From EDS analysis dolomite stained with tartrazine contains 10x more sodium (Na) and sulphur (S) than the original dolomite fragment. This increase is due to the sodium and sulphur present in tartrazine (C16H9N4Na3O9S2). Dolomite stained with congo red (C32H22N6Na2O6S2) contains 0.10% Na and 0.18% S, were the original fragment only contains 0.06% Na and 0.06% S. Although heat was applied in the phase 2 process, a cross sectional evaluation indicated that only the outer surface area of the dolomite was coloured, as was the case in phase 1.

C. Results: Quartzite Staining

Table 3 shows the data obtained from the outer layer EDS analysis for the original quartzite fragment and the fragments stained with ferric chloride and methylene blue in phase 2. From the data it is evident that the ferric chloride stains the quartzite effectively; the iron weight % increases from 0.49% to 44.15% and the chloride weight % increases with 8.24%. Although methylene blue (C16H18ClN3S) coloured the quartzite fragment effectively, the EDS analysis does not show a change in composition regarding chloride and sulphur. An increase in aluminium, phosphorus and arsenic is observed in the EDS analysis.

TABLE III: QUARTZITE ANALYSIS ON THE OUTER SURFACE

	Quartzite Outer Layer– Ferric Chloride												
	Component Weight %												
	Si	O	Ca	Mg	Al	Na	K	Fe	Pd	Cl	S	Br	Cr
Origina l	34.6	50.81	0.49	0.19	11.95	0.12	1.02	0.49	0.36	0	0	0	0
Phase 2	10.46	28.37	0	0	0.59	0	0	44.15	0	8.24	0.51	2.27	5.41

	Quartzite Outer Layer – Methylene Blue										
	Component Weight %										
	Si	O	Ca	Mg	Al	Na	K	Fe	Pd	P	As
Origina l	34.6	50.81	0.49	0.19	11.95	0.12	1.02	0.49	0.36	0	0
Phase 2	22.77	50.20	0	0	15.0	0	0	0	0	7.26	4.77

TABLE IV: QUARTZITE ANALYSIS ON CROSS SECTION

Quartzite Inner Layer– Ferric Chloride											
	Component Weight %										
	Si	**O**	**Ca**	**Mg**	**Al**	**Na**	**K**	**Fe**	**Pd**	**Cl**	**Ti**
Phase 1	31.05	49.67	0.97	0.37	14.48	0.23	1.53	0.98	0.72	0	0
Phase 2	32.98	50.05	0.10	0.07	12.80	0	2.08	1.31	0	0.29	0.32

In phase 1 the colouring of quartzite was only limited to the outer surface, where in phase 2 the colouring of the fragments was observed throughout the cross section of the fragment. This effective colouring is due to the quench-crackling of the quartzite fragments were the fragment was subjected to 700 °C and submerged directly in the cold colouring solution. Table 4 shows the difference in component weight % of the inner layer of the quartzite coloured with ferric chloride from phase 1 and phase 2. It is evident that the iron content increases from 0.98% to 1.31% and chloride increases from 0% to 0.29%.

IV. CONCLUSION

This study evaluates the effect of different colouring methods on mine dump rocks, for aesthetic and economical purposes. The study also evaluates the effect of heat treatment on the colouring process and the weathering rate of the colouring agent. The successful colouring of dolomite and dolerite rock fragments is evident throughout the study. After 60 days exposure to weather conditions the colouring agent on dolomite weathers to the point where the rock surface becomes visible, whereas the original colour of the dolerite remains on the rock surface. It is evident that when the colouring solution is subjected to heat treatment, the colour on the outer surface of the dolomite weathers at a slower rate, although the addition of heat has no effect on the colour of the inside of the rock. The outside layer of the quartzite fragments was successfully coloured in phase 1 and showed slow weathering after 60 days of exposure, but the inner layers remained unchanged in colour. Quench-crackling experiments conducted on quartzite in phase 2 extended the colouring of the fragments to the inner layers of the rock. The weathering rate of the colouring agent was slower in phase 2 although the rock itself become more brittle. Further suggestions include the consideration of increasing the strength of the quartzite fragments while colouring the fragments through quench-crackling.

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REFERENCES

[1] P. K. Oldring, Coatings, Colorants, and Paints. (In R. A. Meyers (Red.), Encyclopedia of Physical Science and Technology 175-190). Academic Press, 2003.

[2] K. Bucher and M. Frey, *Petrogenesis of Metamorphic Rocks*, 7th ed. Heidelberg: Springer Science & Business Media, 2002. https://doi.org/10.1007/978-3-662-04914-3

[3] V. Agarwal, S. Shukla and A. N. Dogne. "Stones - An Architectural Overview," *Journal of Ceramics and Concrete Sciences*, vol. 1, pp. 1-18, 2016.

[4] B. Dutrow and C. Klein, *The Manual of Mineral Science.* 23rd ed. New Yersey: John Wiley & Sons, Inc, 2007.

[5] F. B. Waanders, Dolomite composition, 2018.

[6] Y. Kim and Y. I. Lee, "Characterization of Quartzites in the Southern Korean. Peninsula," *Gondwana Research*, vol. 6, pp. 729-742, 2003. https://doi.org/10.1016/S1342-937X(05)71020-0

[7] L. E. Spock. *Guide to the study of rocks,* 2nd ed. New York: Harper & Row Publishers, 1953.

[8] C. S. Klein and C. Hurlbut. *Manual of Mineralogy*, 20th ed. New Yersey: John Wiley & Sons, Inc, 1986.

[9] D. R. Askeland, P. P. Fulay and W. J. Wright. *The science and engineering of materials*, 6th ed. Stamford: Global Engineering: Christopher M. Shortt, 2011.

[10] M. Naeem, P. Khalid and A. W. Anwar. "Construction material prospects of granitic and associated rocks of Mansehra area, NW Himalaya, Pakistan". *Acta Geodaetica et Geophysica*, vol. 50, pp. 307-319, 2015. https://doi.org/10.1007/s40328-014-0087-z

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